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TECHNICAL NOTE No. I.E.E. 17

# THE DEVELOPMENT OF CASING SEALS FOR FLOTATION GYROSCOPES [U]

by

M. Trapaud

MARCH, 1963

MINISTRY OF AVIATION







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# THE DEVELOPMENT OF CASING SEALS FOR FLOTATION GYROSCOPES

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R.A.E. Ref: IEE 1299/3

## SUMMARY

This note discusses the deficiencies of the piston ring type of rubber seal commonly used in flotation gyroscope casings. Seal design and performance requirements are listed, and several experimental models are described.

Tests were made under various conditions of pressure and temperature, and one of the experimental seals satisfied all the requirements and appeared to be suitable for gyroscope application.

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## 1 INTRODUCTION

1.1 Gyroscopes for inertial navigation systems are principally of the floated element type. These make use of the buoyancy of fluid having a high specific gravity to obtain the required frictionless suspension of the sensitive element.

1.2 The outer casing of the gyroscope, which contains the flotation fluid, includes separate end caps for assembly purposes. Present practice is to seal these end caps with synthetic rubber '0'-rings, but these may not be entirely satisfactory. In one type of gyroscope it has been necessary to impose a life restriction of two years due to the absorption of gas in the fluid; it is suspected that a major portion of this is air which has entered through the seals.

1.3 It was decided to investigate a range of possible sealing methods suitable for gyroscope casings, in order to achieve a more efficient design. The design and performance requirements are listed.

1.4 A number of simple metal-to-metal seals were designed and tested. The use of metal gaskets also seemed promising, and several seals were made using different types of gasket. The suitability in '0'-ring form of the synthetic rubber "Viton A" was investigated, and a two-stage compression seal was designed to incorporate an '0'-ring of this material and a metal sealing band.

## 2 REQUIREMENTS

2.1 The outer casing of a typical floated gyroscope comprises a cylindrical barrel with end caps for assembly purposes. Each cap contains a synthetic rubber '0'-ring in a groove machined at the outer edge to provide a piston type seal against fluid leakage from the casing (see Fig. 1). It is usual to apply a slight positive pressure to the fluid by means of a spring and bellows system. Although this arrangement is neat and a small overall diameter can be achieved, it is not ideal. The sealing pressure is limited since the '0'-ring must be deformed without damage on assembly, and this may detract from the sealing performance. Furthermore, a small annular clearance space is left between the end cap and barrel, and this may harbour contaminating particles and complicate filling with flotation fluid.

2.2 In developing other sealing methods, the following requirements were considered desirable.

(i) The sealing performance in the operating environment should be such that the gas content of the fluid should not rise to saturation level, through the ingress of air, within the life of the gyroscope, typically, 5 years.

(ii) The outside diameter should be as small as possible, for in inertial navigation systems it is important to miniaturise the gyroscopes.

(iii) The casing end caps should be positively located since they provide the mounting fixtures for internal components.

(iv) It should be possible to rotate one end cap in adjusting the float fixed restraints during gyroscope testing.

(v) The casing should be of clean internal design.

(vi) The materials used in '0'-rings, gaskets, etc., should be compatible with the flotation fluid and with the various cleaning fluids used during assembly.

(vii) It should be possible to dismantle conveniently the gyroscope at any stage of proving up to its final acceptance.

2.3 Most of the seals developed were applied to a casing of 82 millimetres internal diameter, with a wall thickness of 5 millimetres. These dimensions approximate to those of a current production gyroscope of inertial navigation quality. A smaller seal for a casing of 35 millimetres internal diameter was also tried, as this dimension was typical of the miniature class of gyroscope.

3 METHOD OF TEST

3.1 In most cases the seals were tested for gas leakage with the inside of the casing evacuated and the outside at atmospheric pressure. A consolidated Electrodynamics Corporation, mass spectrometer type 24-110 was used for leak detection, with helium as the tracer gas. It was necessary to correct the leakage rate for helium gas measured by the detector in order to obtain the equivalent rate for air. Considering the flow through the leak to be of molecular form the correction factor would be:-

$$\text{Leak rate for air} = \text{Leak rate for helium} \times \sqrt{\frac{\text{Density of helium}}{\text{Density of air}}} .$$

In a seal using a synthetic rubber '0'-ring a portion of the indicated leak would be due to diffusion through the '0'-ring material, and the above correction would not be strictly accurate. However, since air diffusion rates for the particular materials used for gyroscope '0'-rings could not be obtained, the correction for molecular flow was applied.

The detector operated over the range $1 \times 10^{-9}$ to $1 \times 10^{-5}$ atmospheric c.c. per second. A maximum leakage rate of 13 c.c. of air in 5 years was allowed, since 13 c.c. of air would saturate the quantity of fluid contained in a current production gyroscope of the larger size. Where sealing performances are reported as unsatisfactory the detector was, in fact, "off scale" and the rates were greater than $1 \times 10^{-5}$ atmospheric c.c. per second (500 c.c. per year).

3.2 The seal to be tested was piped to the gas input of the detector and pumped down to the operating pressure of the instrument, ($< 2 \times 10^{-4}$ m.m. Hg). A polythene bag was used to envelope the outside of the seal and helium gas was injected to give an overall indication of any leakage through the seal, Fig. 2. More precise location of a leak could be made by applying a fine jet of gas to the seal face, and if necessary localizing the detecting area by placing a plastic sleeve over the end of the helium gas jet tube to butt against the seal face.

3.3 The seals were temperature cycled between +90°C and -20°C. Tests for leakage were made with the seal casing as near as was possible to the ultimate soaking temperature, and were repeated when the seal had returned to room temperature.

3.4 The two-stage seal was tested with both negative and positive internal pressure, within the range of $10^{-4}$ m.m. Hg. and 28.7 lb/in$^2$ absolute. In the positive pressure tests a check was made for leakage at the outside of the seal using the detector sampling probe, Fig. 3.

## 4 DEVELOPMENT OF VARIOUS SEALS

### Preliminary tests

4.1 Early in the programme the leakage rate through a standard '0'-ring of D.T.D.5509 (grade 3) Acryonitile rubber, installed in a gyroscope casing of the type shown in Fig. 1, was made at 20°C with a differential pressure of one atmosphere. The leakage rate was approximately $2 \times 10^{-7}$ atmospheric c.c. per second and this indicated that the saturation level of air in the fluid of 13% by volume at N.T.P., would be reached in about two years.

4.2 The effect of cooling Acryonitile rubber '0'-rings in an R.A.E. experimental glass walled gyroscope model was explored. Mechanical failure of the rings occurred at a temperature of +2°C when air was drawn into the model by contraction of the fluid. At -20°C, a large leak developed and it was seen that the '0'-ring had pulled away from the internal surface of the cylindrical glass barrel. Waxing of the fluid prevented the bellows accommodating the contraction.

### Direct metal-to-metal seals

4.3 A joint comprising lapped steel faces bolted together, see Figs. 4 and 5, was manufactured. When the joint was first assembled, a good seal was obtained (leakage < $10^{-8}$ atmos. c.c./second), but this performance could not be repeated after dismantling in spite of lapping the faces again.

4.4 A thin coating of gold was deposited on the lapped faces of the seal, but this proved ineffective. The coating was measured and found to be 50 micro inches thick.

4.5 The sealing pressure on lapped steel faces was increased by using a more robust design, see Figs. 6 and 7, but the sealing performance was unsatisfactory. The lapped face of the sealing plate was tinned with soft solder, but the performance was again unsatisfactory.

4.6 A design incorporating spherical lapped steel faces, Figs. 8 and 9, was tried without success. A flash of copper on the sealing plate was ineffective.

### Metal gasket seals

4.7 An annealed aluminium ring of 1/16 inch round section was imprisoned in a groove formed closed to the internal wall of the casing, see Figs. 10 and 11. The leakage rate was measured at room temperature, at 90°C, and at room temperature after 3 hours at 90°C. In each case it was <$10^{-8}$ atmos. c.c./second.

Sealing was unsatisfactory at -20°C, but the performance was restored upon warming to room temperature. Tests to determine the temperature at which sealing deteriorated were not made.

4.8 A seal incorporating an indium gasket cast in an annular groove in the casing face, see Figs. 12 and 13, was unsatisfactory when the indium was squashed 0.005 inches, but was satisfactory when squashed 0.03 inches. Tests at high and low temperatures made together with those reported in section 4.7 above gave identical results.

4.9 A smaller seal of 36 millimetres diameter incorporating a Wills gas filled ring, see Figs. 14 and 15, was made. The rings used were of two types, stainless steel and nickel plated steel, of 2 millimetres section by 35 millimetres inside diameter and pressurised to 500 lb/sq in. These rings were compressed between two lapped steel faces by tightening the cap screws onto a spacing washer. The performance was unsatisfactory in both cases, even after removing the spacer and tightening the cap screws as much as possible. The use of a Wills ring of smaller section and plated with a soft metal such as gold was considered, but was not tried.

Two stage seal

4.10 This seal, see Figs. 16 and 17, combines a narrow lapped metal-to-metal joint to provide a clean internal surface, an elastic '0'-ring of the inert "Viton A" grade of synthetic rubber and a thin brass swaging band. The band serves to imprison the '0'-ring, locates the end cap, and provides an additional seal when finally swaged over and an adhesive or solder is applied. The exterior is neat and slightly smaller in diameter than the standard design given in Fig. 1. It is described as a two stage seal because it could be used, first, with a temporary clamp across the joint as shown in the Figs. 18 and 19, when adjustment by rotating the end cap of the gyroscope fixed restraints may be necessary during testing. Secondly, after completion of the gyroscope proving tests, the thin band would be swaged over to make a permanent seal and the clamp removed. See Fig. 20.

4.11 With the clamp in place and a dry '0'-ring installed, the seal was subjected to two temperature cycles of +90°C to -20°C, without leakage. The '0'-ring was moistened with a fluorocarbon flotation fluid and the seal was again satisfactory after a further two cycles of temperature testing. The tests were continued with a positive pressure inside the casing. Initially pressurised to 10 lb/in$^2$ at room temperature, the pressures during test were modified by temperature cycling to 8 lb/in$^2$ when cold and 12 lb/in$^2$ when hot. The seal was subjected to two cycles of +90°C to -20°C and was satisfactory. Tests were made in which the seal proved effective during, and after, rotation of the end cap.

## 5 DISCUSSION

5.1 The commonly used piston ring type of rubber seal suffers from several deficiencies. Because of the internal arrangement of the casing, contaminating particles may be harboured and released later to impair gyroscope performance. Filling with the flotation fluid may also be complicated. The pressure applied to the sealing ring must be limited for assembly reasons, and this may affect its performance at low temperatures. Furthermore, there is no barrier against the entry of air by diffusion through the sealing material.

5.2 Of the other designs investigated, none of the metal-to-metal seals were satisfactory using either lapped surfaces in direct contact or when coated thinly with softer metals. Furthermore, unacceptably high sealing pressures and casing stresses had to be applied for any chance of success, and this resulted in clumsy arrangements.

5.3 Work with metal gasket seals was more promising. To obtain satisfactory sealing it was necessary to use casings having stiff sections locally and incorporating the maximum number of pressure screws or a heavy screwed ring. The outside diameter of the casing was limited so as not to exceed that of a standard gyroscope, and it was considered that the design could be refined. The use of heavy sealing pressures would persist, however, and although the high internal stresses would be confined to the gyroscope casing it was considered that these should be avoided if possible.

5.4 The two stage seal, finally manufactured and tested was the only type to meet all of the design and performance requirements listed in section 2.2 above.

## 6 CONCLUSIONS

6.1 Although the design of effective seals for other applications is well understood and these are in daily use, for example, in high vacuum work, a satisfactory solution to the gyroscope problem proved difficult to obtain. This was largely because of the need to miniaturise, and the strict size limitations imposed. It is considered, however, that the two stage seal as developed meets the requirements, and it is intended to incorporate this arrangement in R.A.E., experimental gyroscopes.

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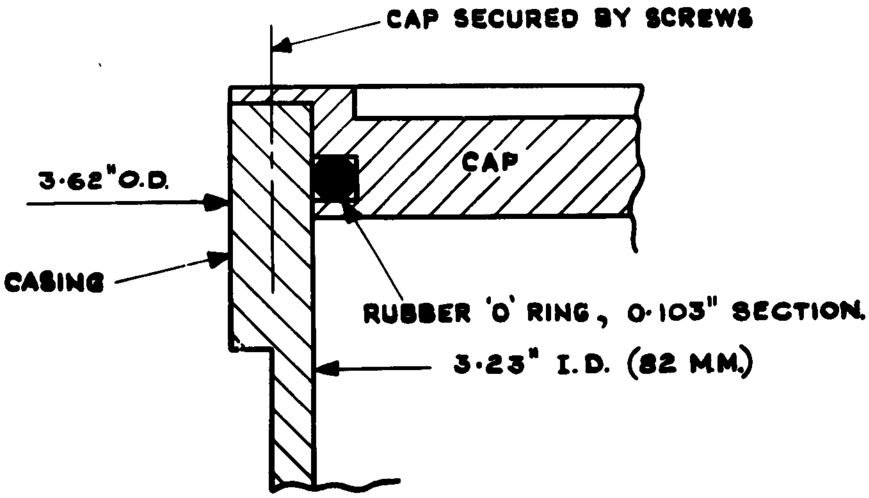


FIG. I. SECTION OF STANDARD PISTON RING SEAL USING RUBBER 'O' RING.

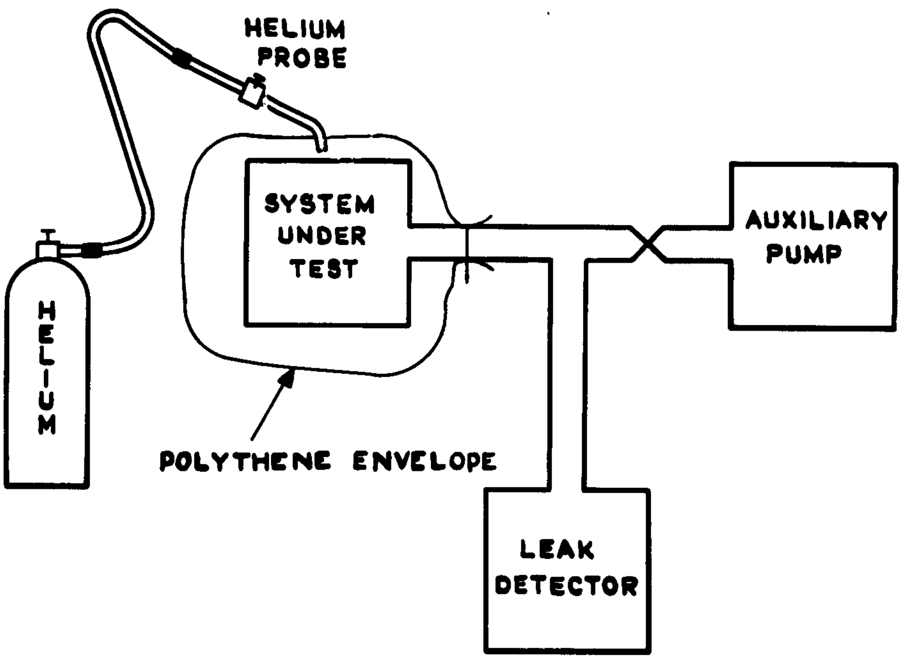


FIG. 2. LEAK DETECTION OF AN EVACUATED SYSTEM.

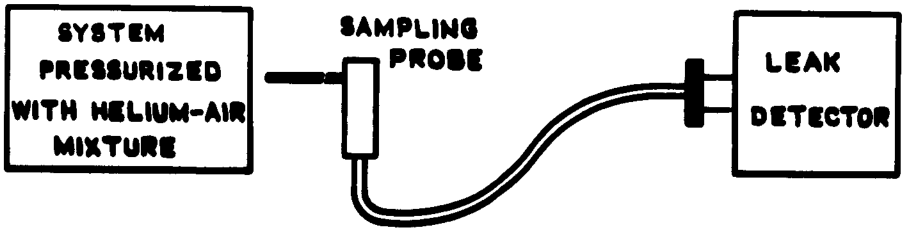


FIG. 3. LEAK DETECTION OF A PRESSURIZED SYSTEM.

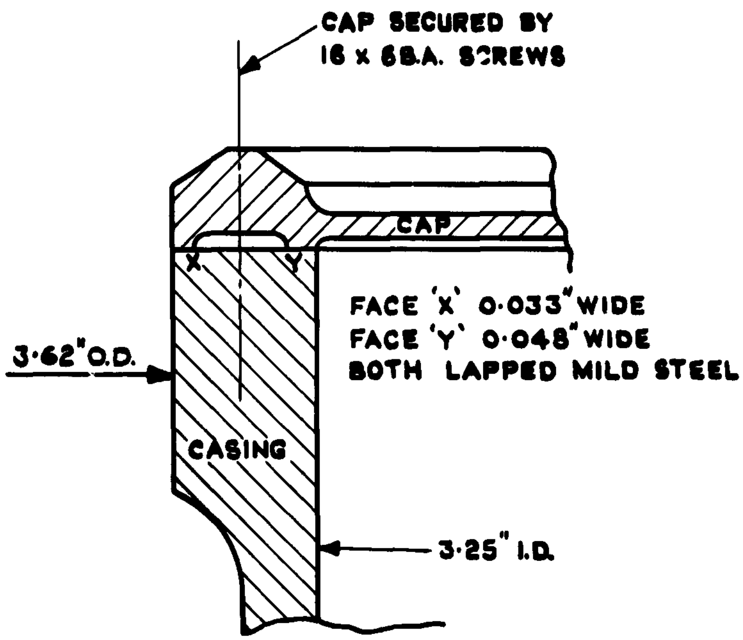


FIG. 4. SECTION OF LAPPED BRIDGE SEAL.

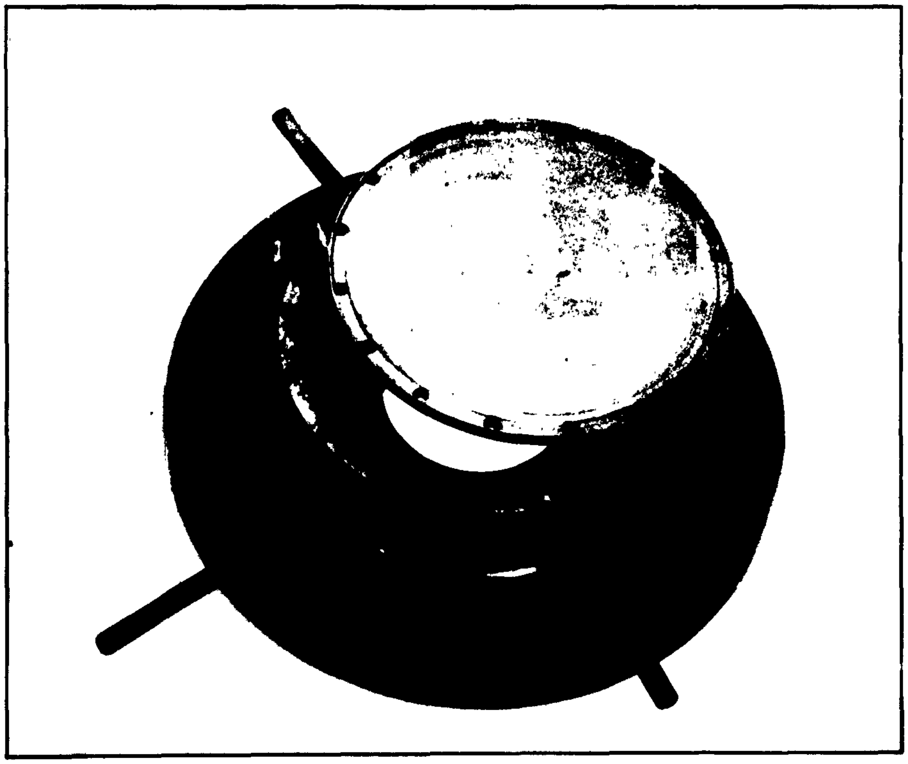

FIG. 5. GOLD PLATED BRIDGE SEAL.

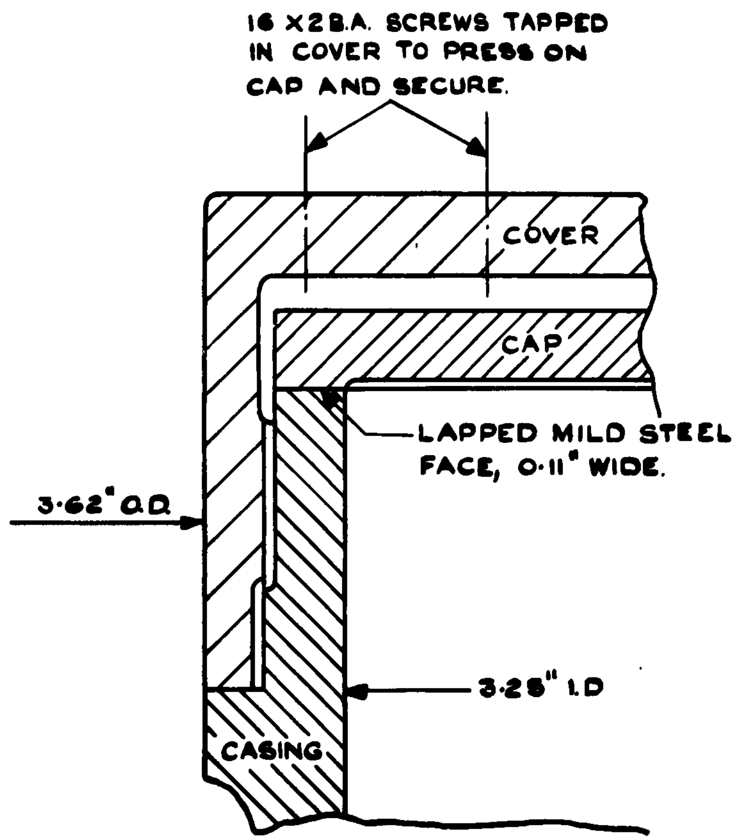


FIG.6. SECTION OF FLAT LAPPED SEAL WITH SCREW CAP

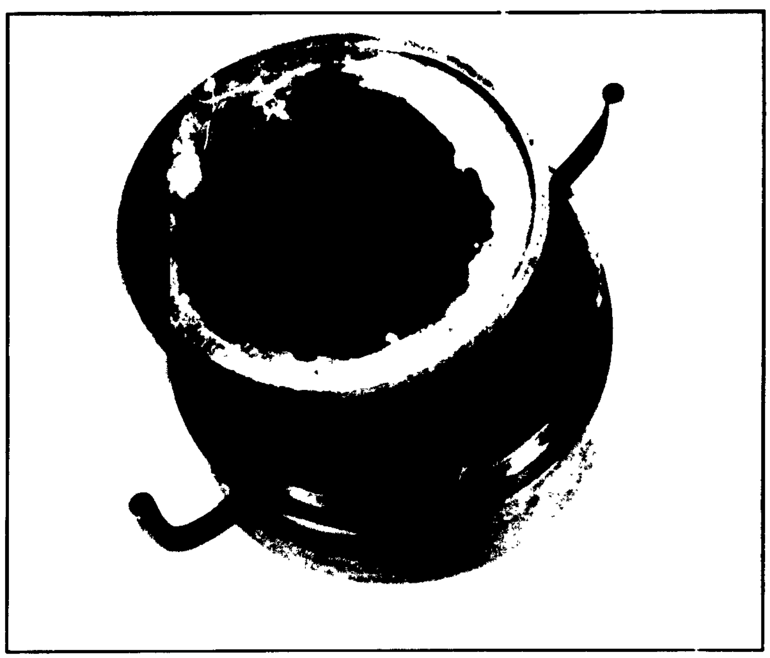

FIG.7. EXPLODED VIEW OF FLAT LAPPED SEAL.

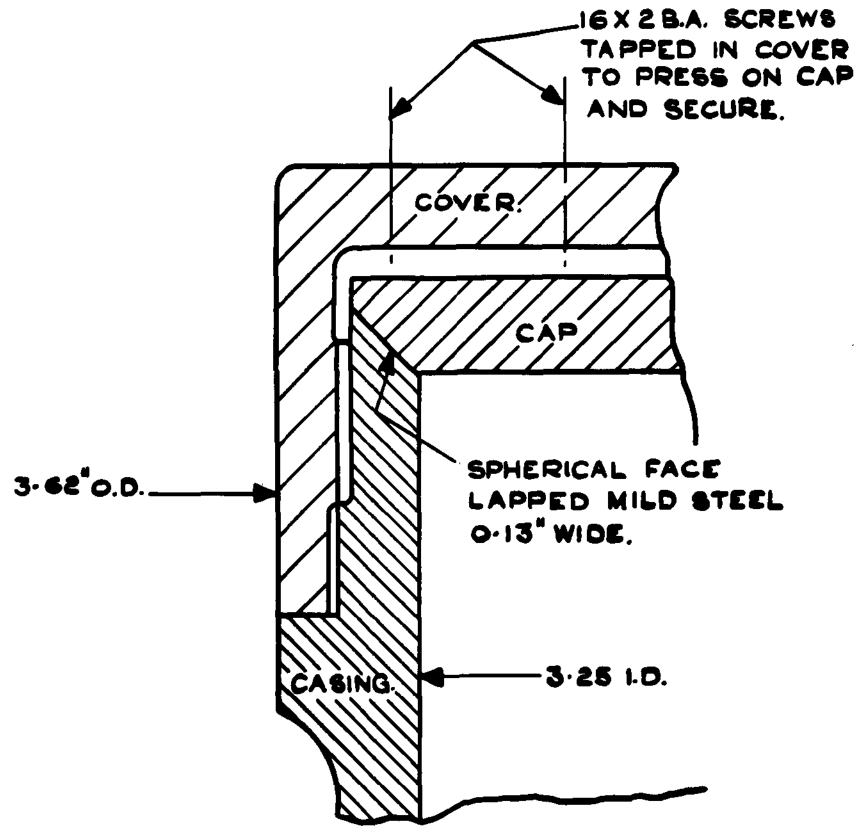


FIG.8. SECTION OF SPHERICAL LAPPED SURFACE SEAL.

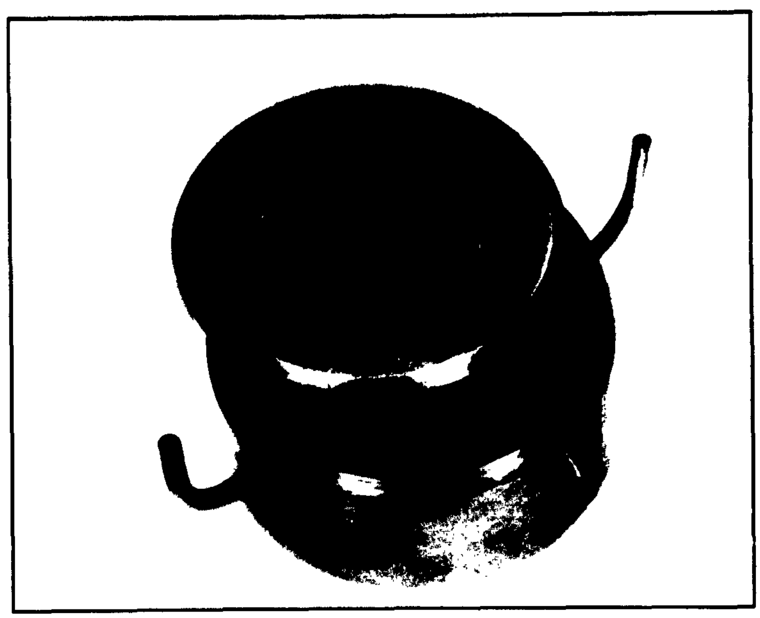

FIG.9 EXPLODED VIEW OF SPHERICAL SURFACE SEAL.

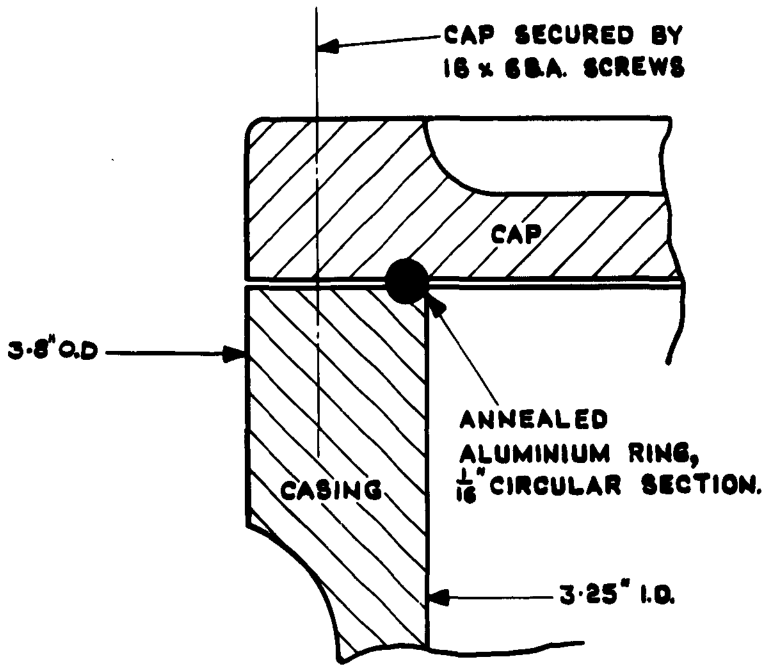


FIG.10. SECTION OF ALUMINIUM GASKET SEAL.

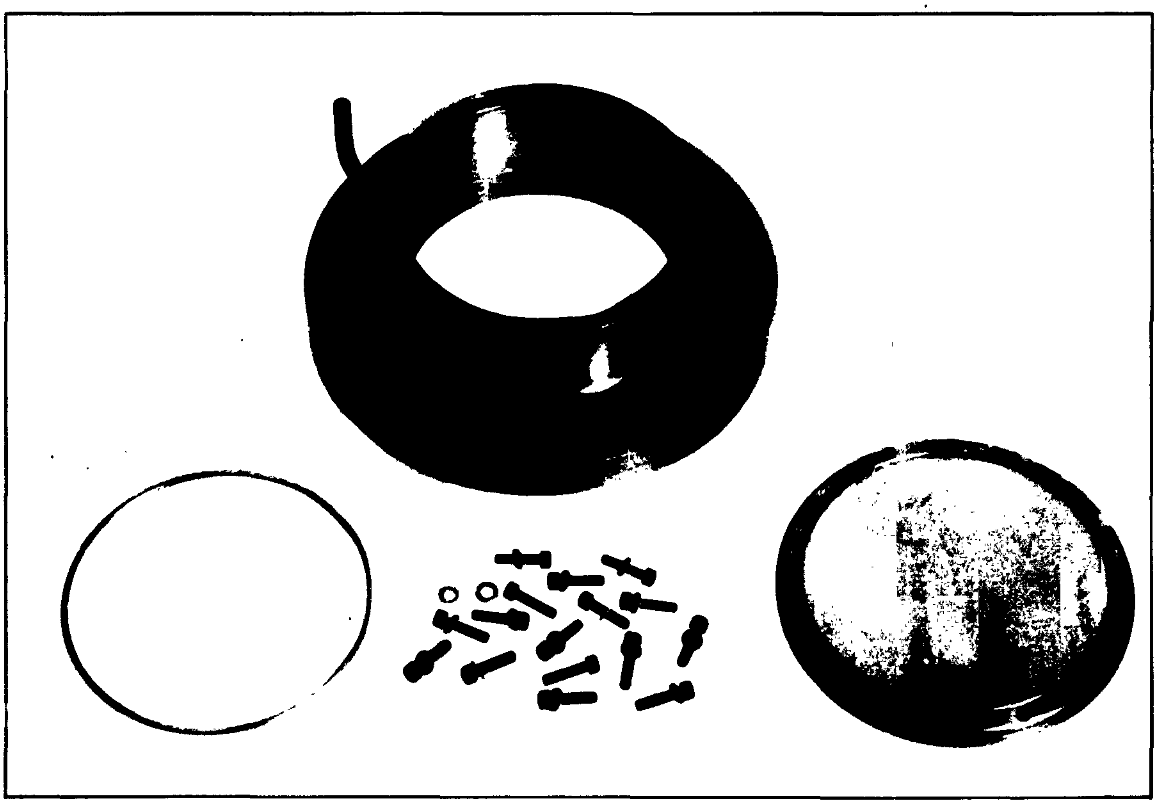

FIG.11. EXPLODED VIEW OF ALUMINIUM GASKET SEAL.

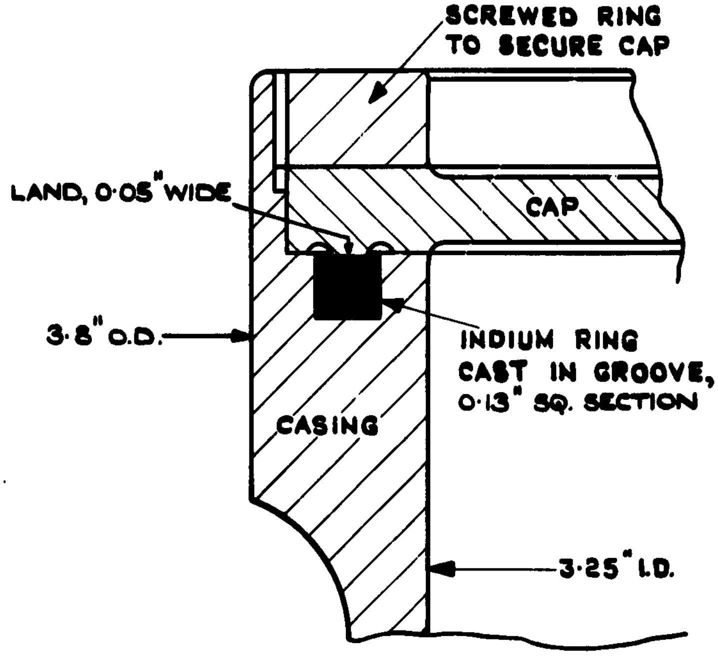


FIG.12. SECTION OF INDIUM METAL SEAL.

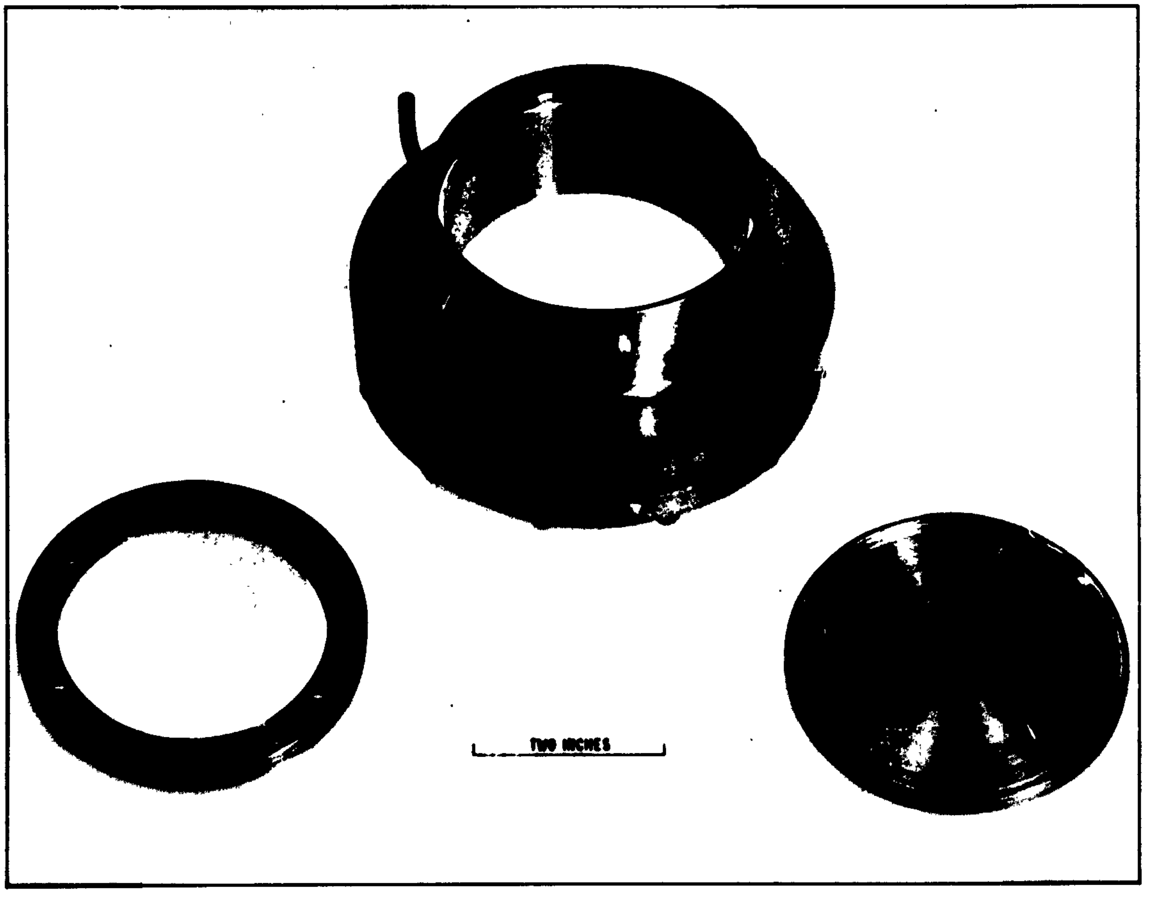


FIG.13. EXPLODED VIEW OF INDIUM SEAL.

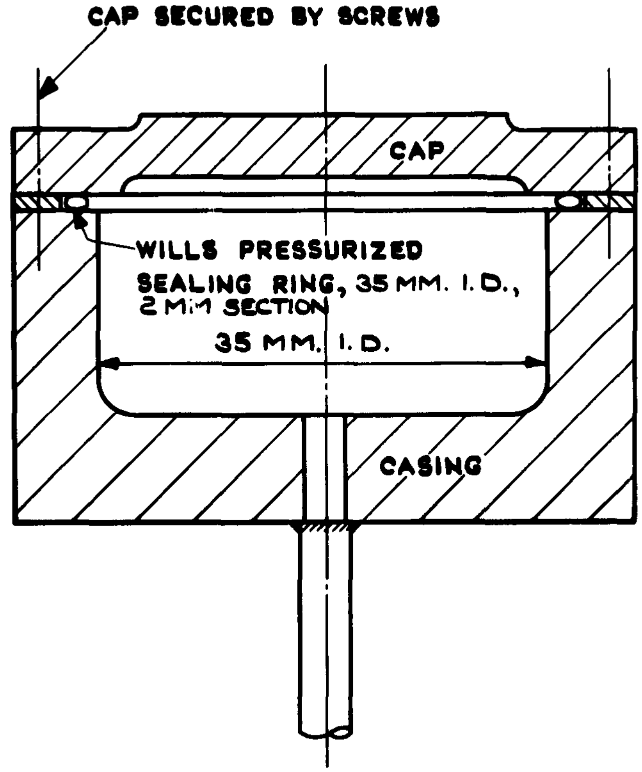


FIG.14. SECTION OF WILLS RING SEAL.

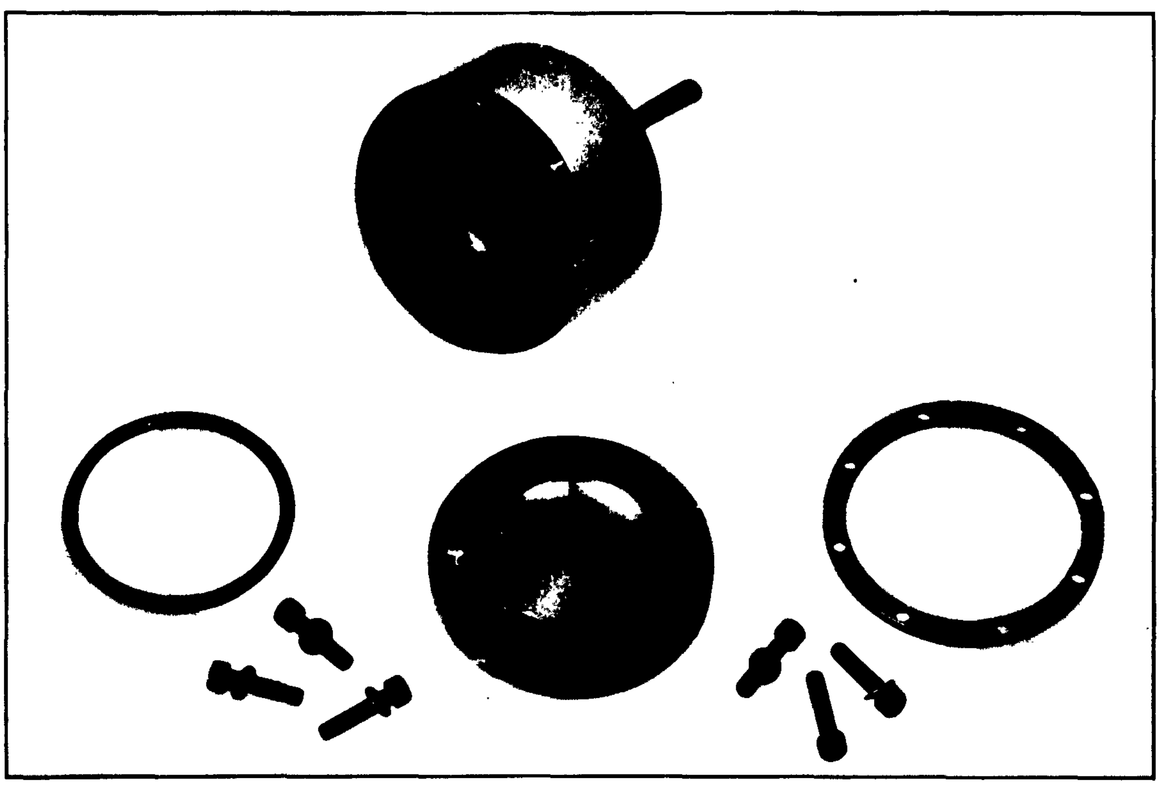

FIG.15. EXPLODED VIEW OF WILLS RING SEAL.

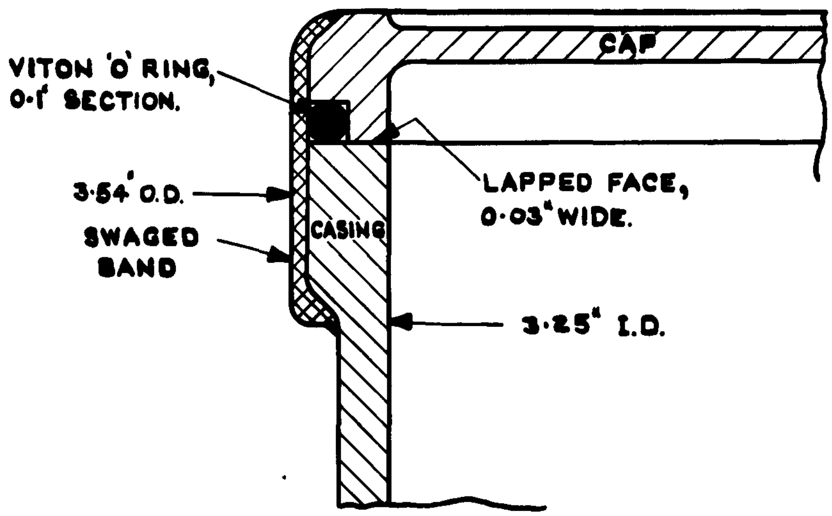


FIG.16. SECTION OF TWO-STAGE SEAL.

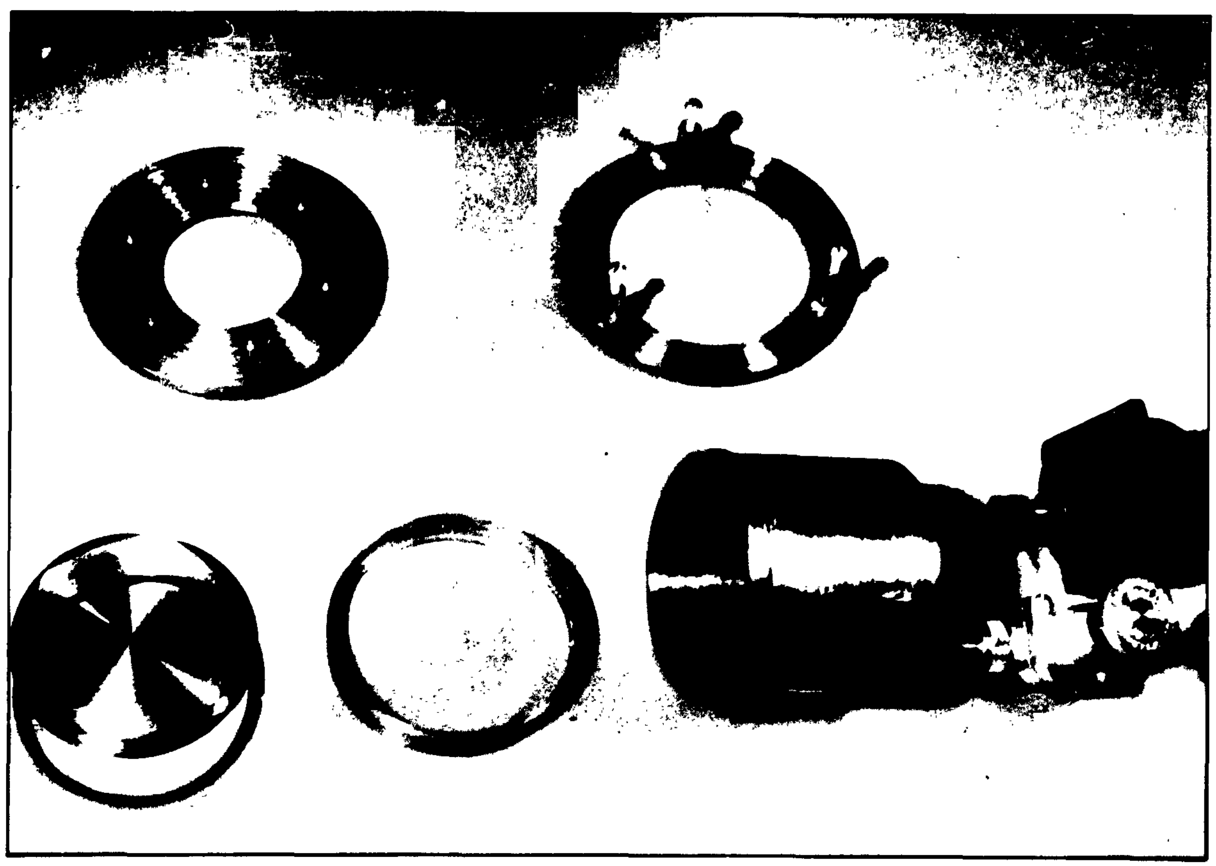

FIG.17. EXPLODED VIEW OF TWO-STAGE SEAL AND CLAMPING-RING.

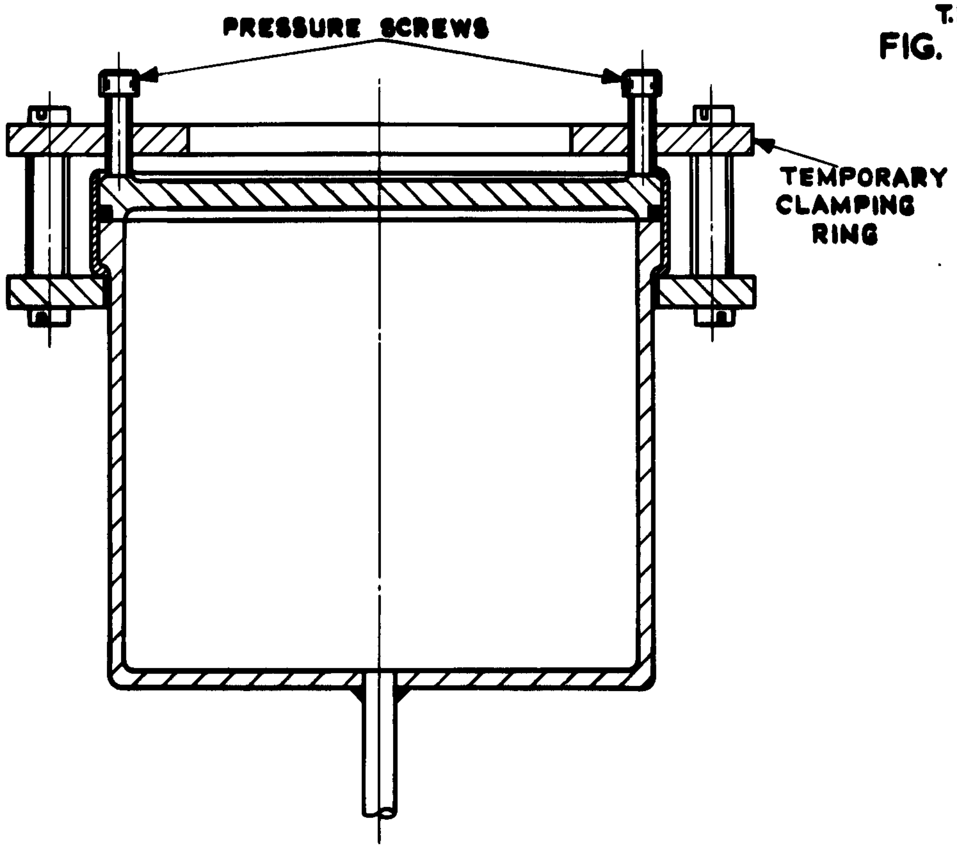


FIG.18. SECTION OF TWO-STAGE SEAL WITH CLAMPING RING.

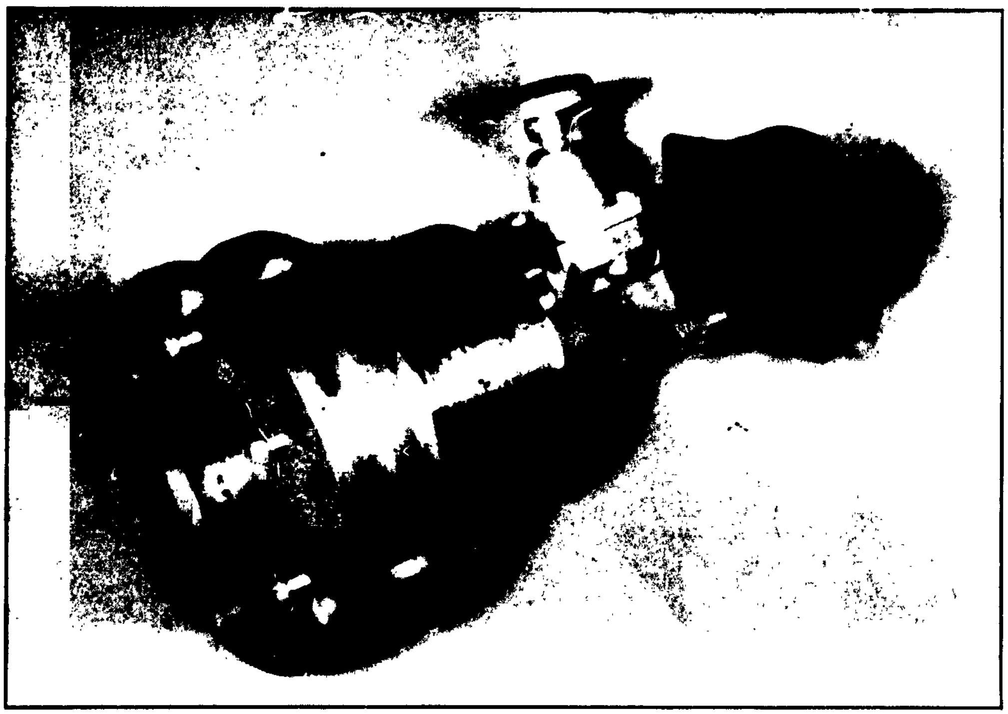

FIG.19. TWO-STAGE SEAL AND CLAMPING RING ASSEMBLY

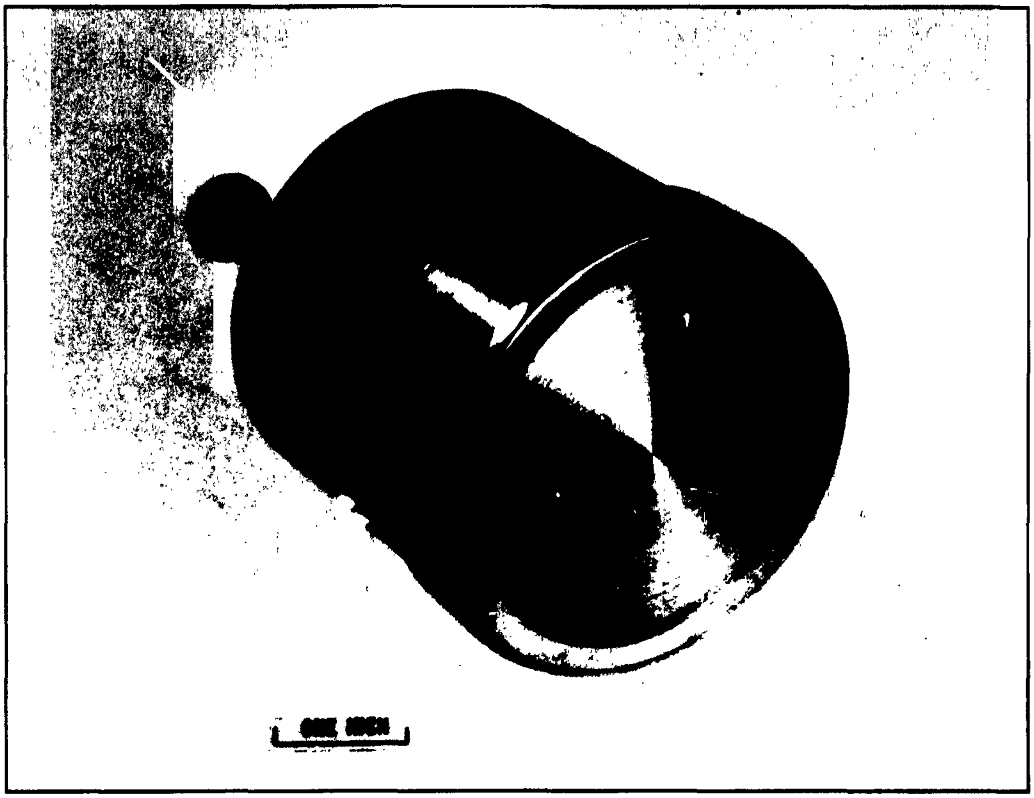

FIG.20. TWO-STAGE SEAL AFTER FINAL SWAGING

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